Understanding the Impact of Surface Waves on Microwave Water Level Measurements

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Abstract- **The National Oceanic and Atmospheric Administration (NOAA) Center for Operational Oceanographic Products (CO-OPS) has been conducting a series of tests of several different types Microwave Water Level (MWWL) sensors in order to gain an understanding of sensor functions and performance capabilities and to assess the suitability for incorporation of these sensors into the NOAA National Water Level Observation Network (NWLON). On March 5-6, 2008, one particular laboratory test of four different microwave sensors was conducted with the following objectives: 1) determine the impact of surface gravity waves on the accuracy of measured water level and 2) collect a data set that can be used to develop techniques for removing high frequency surface wave induced noise from long term microwave water level records. The two day test was conducted at the Naval Surface Warfare Center (NSWC) Maneuvering and Sea Keeping Basin (MASK) in Carderock, Maryland. This facility includes a 110 m long, 73 m wide, 6.1 m deep indoor tank, with the capability to generate controlled, multi-directional surface waves. During the test, the four sensors measured water level in the tank from above, at four different sensor-to-water ranges, 3, 5, 7, and 9 meters. At each measurement height, a range of different surface wave conditions were generated in the tank, including regular controlled wavelength waves as well as irregular waves, simulating real ocean conditions. Results indicate that in some cases, continuously generated uniform wavelength waves caused offsets in measured water level for all sensors, and these offsets depend on the ratio between the width of the sensor footprint on the water surface and dominant wavelength of surface waves present. The impact of surface waves on measured water level varied across different sensors, due to different filtering and range tracking algorithms employed. Results will be used to gain a better understanding of sensors' processing capabilities and to ensure that each sensor's parameters are optimally configured for additional future field tests. A detailed overview of the setup and execution of this unique laboratory test will be presented along with analysis results summarizing the observed wave induced offsets. Recommendations on filtering methods for removing high frequency surface wave induced noise from long term MWWL measurements will also be discussed.**

I. INTRODUCTION

Over the past two hundred years, water level observations have been collected and used to help mariners navigate oceans and estuaries, cartographers develop nautical charts, government agencies regulate boundaries, and scientists gain a better understanding of various physical processes in the ocean. An important mission of the National Oceanic and Atmospheric Administration (NOAA) Center for Operational Oceanographic Products (CO-OPS) is to support those who depend upon these data by providing the most up-to-date water level products and services available. As technology evolves and improved methods for collecting water level are developed, CO-OPS facilitates the transition of new technology to an operational status, selecting newly developed sensors or systems from the research and development community and bringing them to a monitoring setting. This process starts with CO-OPS conducting a series of rigorous tests and evaluation of a newly developed sensor.

Methods for collecting water level data began with the tide staff and human observer and gradually evolved to tide gauges that required less human intervention. Today float/shaft angle encoders, as well as acoustic and pressure sensors are used to collect data at NOAA's National Water Level Observation Networks (NWLON) stations. Current NWLON sensors measure water levels with an accuracy of 1 cm for each standard 3 min average sample [1] and long period averages provide accuracies that make it possible to estimate the global sea level rise at 0.15 cm per year. Although current NWLON instruments have served NOAA well, they are not without disadvantages. For example, most sensors used today are in contact with the water, making them susceptible to corrosion and bio-fouling.

Recently developed microwave altimeter technology offers the opportunity to overcome one of the largest disadvantages of currently-used water level sensors by avoiding contact with the harsh marine environment and the resulting physical damage. An out of the water sensor setup will also result in significantly lower installation costs and potentially less maintenance requirements as compared with existing subsurface sensors.

Several manufacturers offer microwave technology appropriate for measuring water levels and CO-OPS has selected the systems of four manufacturers for testing. CO-OPS has been conducting a series of ongoing tests in order to understand microwave sensor functioning and performance capabilities and to assess the suitability for incorporation into NOAA NWLON [2,3]. Microwave sensors tested will be required to measure water level with a minimum accuracy of 1

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cm. Based on manufacturer's specifications and previous test results, they are expected to be even more accurate than currently used sensors.

One particular phenomenon that needs to be assessed and quantified during testing of microwave water level (MWWL) sensors is the impact of surface waves on measurements. On March 5-6, 2008 CO-OPS conducted an experiment at the Naval Surface Warfare Centers (NSWC) Maneuvering and Sea Keeping Basin (MASK) facility for the purpose of observing this phenomenon in a controlled laboratory setting. Data will be used to gain a better fundamental understanding of the interaction of microwave signals and a rough water service and to develop techniques for removing high frequency surface wave induced noise from long term microwave water level records while retaining low frequency signals (such as tides, wind setup, etc). This paper presents a description of the laboratory test operations, a summary of analysis results conducted to date, and NOAA CO-OPS plans for continuing work.

II. Description of Sensors Tested

There are two types of microwave altimeters most commonly used in current applications, the pulse and the frequency modulated continuous wave (FMCW). Pulse sensors transmit a series of single pulse signals that measure water based on the time of flight of the reflected signal from the water surface. FMCW sensors continuously transmit a FM chirp signal and calculate water level based on the phase shift between the transmitted and reflected signals.

Over the past decade CO-OPS has closely followed the developing microwave water level technology and has conducted and monitored several extensive tests of these devices [2-7]. Based upon experience both within NOAA and outside organizations, CO-OPS has selected sensors from four manufacturers to be included in the water level measurement test and evaluation effort: 1) Miros SM094, 2) Design Analysis H3611, 3) Ohmart/Vega Vega Puls 62, and 4) the Sutron RLR-0001 (The use of brand names in this paper is for the purpose of identifying sensors only and does not imply endorsement by NOAA). Table 1 summarizes the attributes of the four selected sensors.

Table 1. Characteristics of the four microwave sensors selected for testing.

Sensor Make/Model	Signal Type	Beam Angle (deg)	Max Range (m)
Miros SM094	CWFM	10	10
Design Analysis H3611	Pulse	10	22
Ohmart/Vega VegaPuls	Pulse	8	10
Sutron	Wideband Pulse	32	18.5

Sensor Performance Considerations

Two parameters that will significantly impact the effect surface waves on microwave water level measurements are: 1) the microwave sensor footprint width on the ocean surface and 2) the wavelength of the gravity waves present on the ocean surface. Microwave sensor beams are dispersive, so the size of the sensor footprint on the ocean surface increases linearly with range. Manufacturer specified beam spreading angles for the four sensors to be tested (listed in Table 1) were used to calculate surface footprints as a function of range from the detected surface. The relation between beam spreading angle, α, sensor range from a surface, R, and foot print size, X is depicted in Figure 1. Footprint width as a function of sensor range from the ocean surface was calculated using the following expression:

$$X = 2R\tan\frac{\alpha}{2}$$

Figure 2 shows a plot of calculated sensor footprint size as a function of sensor distance from the ocean surface, for the four sensors tested. The Miros and Design Analysis H3611 sensors have the same beam angle, and hence the same footprint values.

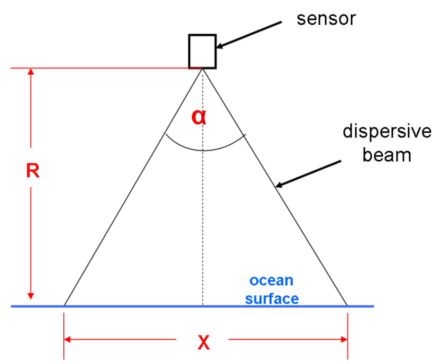

Figure 1. Depiction of the relation between beam spreading angle, α, sensor range from ocean surface, R, and sensor foot print size, X.

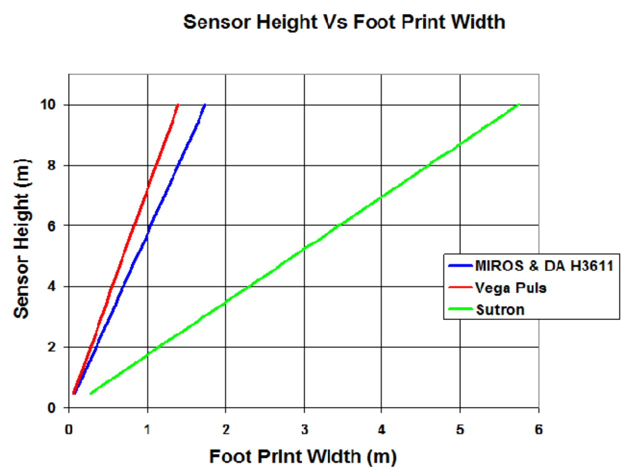

Figure 2. Sensor footprint versus range to water surface, based on specified beam spreading angles list in Table 1.

Previous research focused on using microwave sensors to measure surface waves indicates that a given sensor can only resolve surface waves of wavelengths 4 times the sensor footprint and larger [7]. Waves shorter than four times the footprint width will be averaged out of the sensor's water level reading. The focus of the test discussed here however is not to measure surface waves, but to determine the effect of high frequency surface waves on long term water level measurements and to develop processing techniques to eliminate high frequency surface wave induced noise from the records (the potential to obtain useful surface wave measurements from microwave sensors is of interest, but not a high priority). With this focus, this previous finding [7] suggests that waves with lengths shorter than 4 times the beam footprint will induce minimal noise in water level measurements, while longer waves, relative to the sensor foot print size, will more than likely create significant noise in the water level record. As discussed in the following section (Section III C, "Test Run Summary"), these considerations along with sensor specifications were used to design the different runs conducted during this experiment.

III. Experiment Details

A. *Description of MASK facility*

The MASK facility at NSCW Carderock, Maryland consists of an indoor basin of length 110 m, width 73 m , and depth 6.1 m (except for a 10.7 m deep by 15.2 m wide trench parallel to the long side of the basin), with an overhead traveling crane over the basin centerline. The basin is spanned lengthwise by a bridge on a rail system that permits the bridge to traverse across half of the basin width. Two sides of the basin (one 110 m and one 73 m side) are equipped a series of pneumatic type wave maker units that can be operated in unison or individually. 1D waves can be generated from either individual side of the tank or a 2D wave field can be generated by creating waves from both sides simultaneously. Constant wavelength waves from 1.25 to 10 m in length and up to 0.6 m in height can be continuously generated and random surface realizations for a specified wave frequency spectrum can be generated over time. In order to prevent the occurrence of wave reflections, along the full length of the two basin sides opposite of the wave makers there are 12 degree sloping wave absorbers, made up of seven permeable layers of rectangular precast concrete bar panels resting on impermeable "beaches."

During the experiment, high resolution wave measurements were obtained by six MASK facility ultrasonic transducers that were mounted across the length of the bridge, looking downward at the water surface. These transducers measured point water surface heights at 24 Hz.

B. *Sensor Setup*

The four microwave sensors tested were mounted on a flat plywood platform, which was designed to be suspended above the water surface with sensors looking vertically downward (see Fig. 3 and 4). The sensor mount was then hung from the overhead crane that spanned the lengthwise range of the tank, as shown in Figure 4, which was used lift sensors to change measurement heights across the set of runs (run details discussed in the following section). When hung from the crane, the sensor mount was located nearby the traversing bridge, so the bridge could be moved over to access the sensors between runs in order to make adjustments or check instrumentation as necessary. Special care was taken to ensure that the sensor platform remained motionless and in the same position throughout the duration of each separate run. Tag lines were run from the sensors and attached to the bridge for this purpose and sensor cables were run along the tag lines, back to data acquisition units which were kept on the bridge.

Two internally recording Seabird SBE26plus sensors containing ParoScientific pressure sensors were deployed by NOAA in the MASK test facility during the experiment to provide an additional source of water level measurements. One sensor was deployed on the traversing bride to measure atmospheric pressure in the building and the other was deployed at the bottom of the MASK tank, nearby the microwave sensors field of view, to measure pressure from the bottom of the tank. Clocks on the two Seabird sensors were synched and both collected 1 Hz pressure data, which was later combine and converted to water level measurements.

C. *Test Run Summary*

The two parameters discussed above, the size of sensor footprints on the water surface and the dominant wavelength of surface gravity waves present, were taken into consideration to design the runs conducted during this experiment. In order to vary the size of sensor footprints on the water surface, measurements were collected at four nominal sensor-to-water surface heights, 3, 5, 7, and 9 meters. Resulting footprint sizes of each sensor for these heights are summarized in Table 2 (individual points taken from plot in Fig. 2).

At each measurement height, a series of different surface wave conditions were generated in the tank. Each surface condition was generated for approximately 20 minutes, while microwave sensors were measuring water levels. First, regular waves for a specified wavelength were generated continuously over a series of runs with wavelengths ranging from short waves, smaller than 4 times sensor footprints, to longer waves

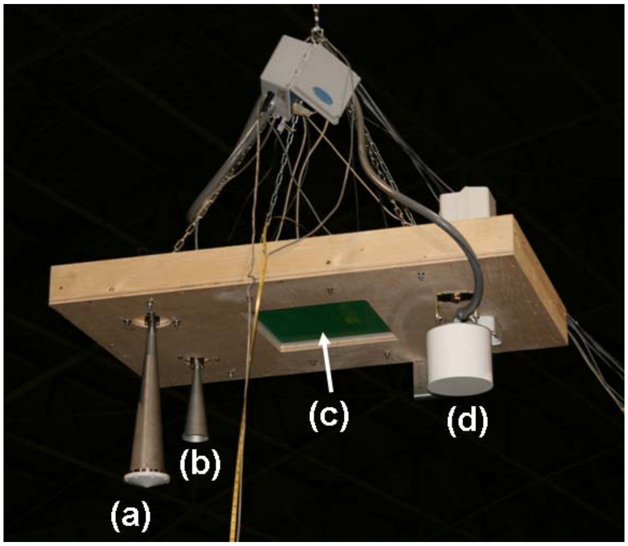

Figure 3. Picture looking upward at the four MWWL sensors in the plywood mount, hanging from the MASK overhead crane: (a) Ohmart/Vega Vega Puls 62, (b) Design Analysis H3611, (c) Miros SM094, (d) Sutron RLR-0001.

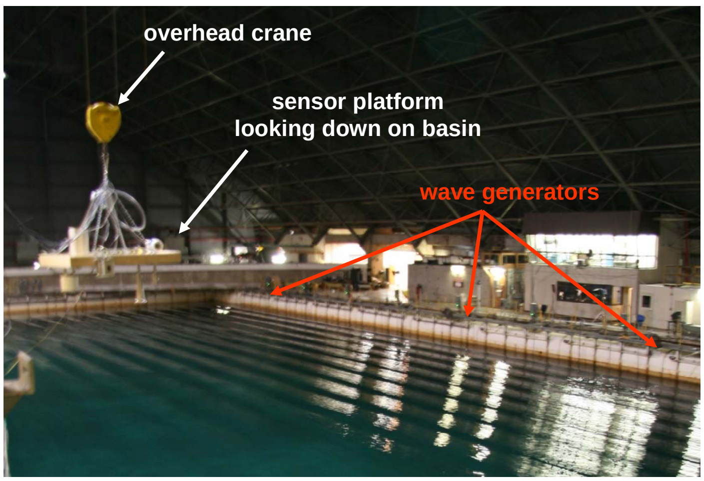

Figure 4. Picture showing sensor platform, suspended from overhead crane, with sensors looking down on the water surface; regular waves are being generated from the long side of the tank.

that are expected to create significant noise in the water level time series, and finally, a 1D random wave realizations based on a selected preprogrammed ocean-like wave frequency spectrum were generated, to simulate real ocean-like conditions. The series of surface wave conditions generated at each sensor measurement height are summarized in Table 3. After all of these listed wave conditions were completed for a given sensor platform height, the crane was used to move the sensor platform to the next nominal height, and the series of wave conditions were repeated. An electronic tape gauge (ETG) was used in order to adjust sensors as close as possible to the four nominal measurement heights. For each adjustment, a specific length of the ETG was hung from the sensor platform and an attendant on the bridge monitored a small ETG electronic display screen while in radio contact with the crane operator, instructing small height adjustments. After the nominal platform height was obtained, tag lines were tended to, and special care was taken to ensure that the sensor platform came to rest and remained motionless before starting the next set of runs.

After all runs for the wave conditions in Table 3 were completed at the four measurement heights, an additional set of runs were conducted at the final 9 meter height (also listed in Table 3) First a series of short steep waves were created in order to cause wave breaking and white capping throughout the tank and then a series of 2D ocean-like wave fields were generated be creating waves based on pre-programmed spectra from both wave-making sides of the tank. As with other runs, these additional conditions were generated for approximately 20 minutes.

Table 2. Width of sensor footprints on water surface for the four selected measurement heights; based on specified beam widths in Table 1

Footprint widths for different sensor heights (m)

Sensor Heights	3 m	5 m	7 m	9 m
Miros	0.525	0.875	1.225	1.575
DA H3611	0.525	0.875	1.225	1.575
Vega Puls	0.420	0.699	0.979	1.259
Sutron	1.720	2.867	4.014	5.161

Table 3. Summary of wave conditions generated at each measurement height. Three extra runs were conducted for the final sensor height at 9 m.

Wave conditions generated at each sensor height, 3, 5, 7, & 9m

Run #	Wave Condition
1	Calm surface, no waves
2	Controled, single direction Smallest wavelength ~1.25 m
3	Controled, single direction Wavelength = 2 m
4	Controled, single direction Wavelength = 10m
5	Irregular ocean wave simulation, from single direction, pre-programmed spectrum

Extra wave runs conducted at 9m height

6	Irregular, short waves, from one direction, breaking/white capping
7	Irregular ocean wave simulation, multi-directional
8	Irregular ocean wave simulation, multi-directional, while slowly changing tank water level

IV. Observations

A. *Water Level Time Series*

Figure 5 and 6 show examples of time series of water level fluctuations measured by each microwave sensors. Water level records were obtained by simply demeaning measured sensor-to-water range. Fig. 5 shows data from the first set of runs with the sensor platform at approximately 3 m above the water surface and Fig. 6 from the final run, with the platform at approximately 9 m. Fluctuations in MWWL measurements clearly mark times of different wave conditions (Table 3). Annotations at the top of each figure (red text with arrows) specify the wave conditions corresponding to each period of water level fluctuation. (Note: as shown in Fig. 5, during the first run, 2m waves were accidentally generated first, before the 1.25 m waves. All participants were fully aware of the reverse order, which was recorded, so there is no impact on resulting analysis).

Plots show that both the Miros and Sutron sensors [(a) and (b) respectively in Fig. 5 & 6], have a relatively fast time response compared to the Design Analysis and Vega Puls, and these sensors resolve more of the wave induced water level fluctuations. Both the Design Analysis and Vega Puls, show a significantly slower time response, which NOAA participants later learned was a result of built in filtering and tracking algorithms employed by these sensors when they are set up as is, "out of the box." During runs with regular 10 m long waves, the Vega Puls appears "lock on" to either the crests or troughs of the continuous wave train, flipping back and forth from one to the other, which is also thought to be a result of signal processing settings that may not be optimal for this application. NOAA CO-OPS plans to use these results to learn more about sensors settings and work with vendors to ensure that sensors are set up more optimally for future testing.

B. *Frequency Spectra of Water Level Measurement*

Figures 7 (a) and (b) show an example of water level frequency spectra calculated for both the microwave sensors and the MASK ultrasonic transducer that was located the closest to the microwave sensors (there was not an ultrasonic sensor exactly co-located with the microwave sensors, but comparison of all ultrasonic records indicates that wave conditions did not vary significantly across the center of the tank, so for purposes here it was adequate to just select the closest ultrasonic sensor). Both plots show data from the run where ocean like waves were generated using the pre-programmed spectrum ("Run 5" in table 3) Fig. 7(a) is for the run with sensors at 3m and Fig 7(b) at 9m. Power spectral density was calculated using the MATLAB Fast Fourier Transform (FFT) function. An FFT window of 256 points was applied to 1 Hz microwave data (~4.25 minutes; 128 point window used on 0.5Hz VegaPuls data) and a window of 8192 points was applied to 24 Hz ultrasonic data (~ 5.7 minutes). A 50% overlap was applied to all windowed data.

The PSD of the ultrasonic transducer measurements (green line with circle markers) is representative of the preprogrammed ocean-like spectrum that was used in the MASK facility to generate waves for these runs (Run #5 in Table 3). Wave energy is mostly in the 0.25 to 0.47 Hz band with peak frequency at approximately 0.3-0.32 Hz (~ 3 second dominant wave).

Calculated PSD for microwave sensor measurements provide insight in to sensor temporal and spatial resolution resulting from time response and footprint size, respectfully. As a result of the Miros sensor's fast times response and smaller footprint at the 3 m height, the Miros PSD in Fig 7(a) (black line) shows that the sensor was capable of measuring the energy resulting from surface wave fluctuations relatively accurately. Fig. 7 (b) shows that the Miros also resolves most of the wave energy during the 9 m run, but spectral levels are a bit lower than those of the ultrasonic sensor, which most likely results from the increase in the Miros footprint size and decrease in spatial resolution.

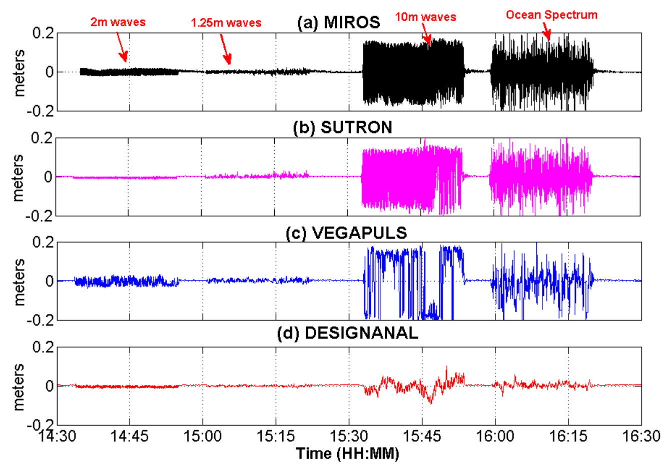

Figure 5. Time series of water level fluctuations from run with sensor platform at **3m**; (a) Miros SM094 (b) Sutron RLR-0001 (c) Ohmart/VEGA Vega Puls 62, and (d) Design Analysis H3611.

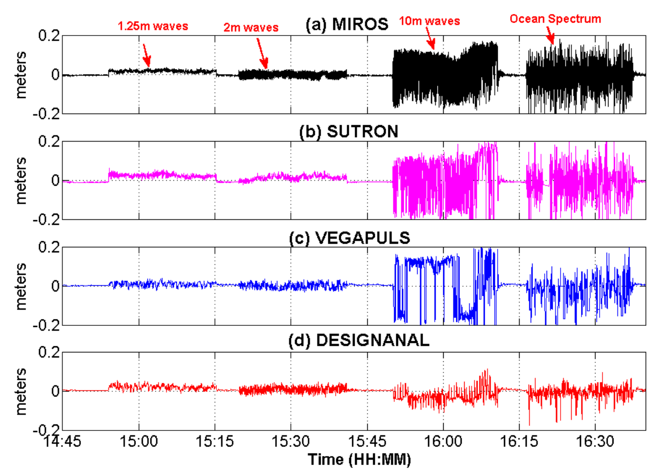

Figure 6. Time series of water level fluctuations from run with sensor platform at **9m**; (a) Miros SM094 (b) Sutron RLR-0001 (c) Ohmart/VEGA Vega Puls 62, and (d) Design Analysis H3611.

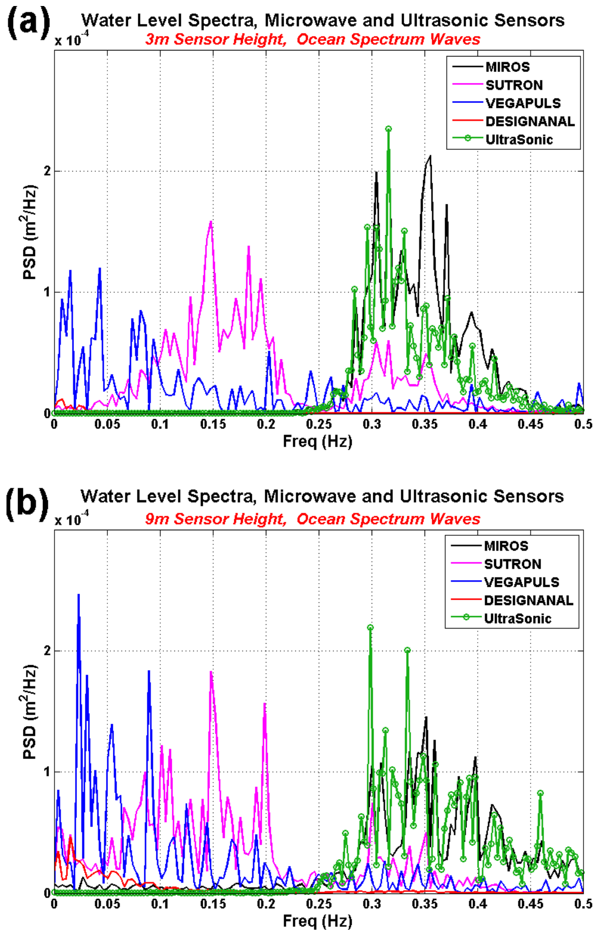

Figure 7. Power spectral density of water level measurements from microwave sensors and MASK high resolution ultrasonic sensors (green line with circle markers); data is from runs with waves generated from preprogrammed ocean-like spectra with sensor platform at (a) 3 meter and (b) 9 meter heights.

The PSD of Sutron measurements (pink line) from both runs indicate that this sensor is capable of resolving some of the wave energy in the 0.25 to 0.47 Hz, but some energy is bled into lower frequencies around ~ 0.1-0.2 Hz. This is more than likely due to low frequency aliasing resulting from the sensor's large footprint and limited spatial resolution. This aliasing is not an issue of concern however, for applications of interest here (recall, the goal is not to obtain wave measurements, but to obtain accurate long term water level records from which high frequency gravity wave induced fluctuations can be removed). The aliased wave energy is in a frequency band that is significantly higher than processes that CO-OPS is interested in measuring (for example tides, wind setup, and storm surge), so in this instance, surface wave noise could be easily filtered out of a data record. The Sutron vendor recently made 10 Hz data available from these test runs (had been internally recorded in the sensor) which may better resolve wave energy due to higher temporal resolution. These data will be analyzed in subsequent work.

Due to slow time response, it can be seen that the Vega Puls and Design Analysis sensors do not resolve any high frequency wave energy, which is expected, due to previously mentioned filtering and tracking settings in these sensors. Once again, this is not necessarily of concern for this application so long as time is taken to clearly understand the details of sensors' built in filtering functions and it is confirmed that the resulting time averaging/slow response will only result in some preliminary reduction of high frequency wave induced fluctuations.

C. Wave induced offsets

During some test runs, an offset in microwave measured range is observed at the onset of wave generation. Instances of these offsets appear in records of all four sensors. A qualitative look at microwave time series, similar to plots in Fig. 5 and 6, show cases of wave induced offsets in the form of both increases and decreases in range at the onset of wave generation. Such offsets appear to be most pronounced during runs with regular, short wavelength waves (waves are characterized by narrow band spectrum). Figure 8 shows some individual examples of such offsets for different runs and sensors [(a) Miros, (b) Sutron, (c) Design Analysis, and (d) Vega Puls]. Initially, there was some thought of the possibility of wave generating mechanisms in the MASK facility causing an actual change in tank water levels, however, averaged water level records from both the NOAA SeaBird pressure sensors and the MASK ultrasonic transducers indicate that no such shift in water level occurred. Based on this result, the assumption was made that the shift observed in MWWL data is a result of sensor bias in the presence of surface waves.

Wave induced range offsets were quantified for all sensors across all runs and then related to wave condition and sensor footprint characteristics. A simple technique was used to calculate each sensor's offsets across test runs. First, an average water level was calculated from the period with calm conditions, just before the start each run (calm periods between run apparent in water level records shown in Fig. 5 and 6), then an average water level was calculated across the following ~ 20 minute long run during which waves were generated. The two average levels were differenced to obtain an offset value.

Figure 9 shows a plot of wave induced offset versus the ratio of the dominant surface wave wavelength during a given run and sensor foot print width, for the (a) Miros, (b) Sutron, (c) Design Analysis, and (d) Vega Puls sensors. In these plots, the left end of the X-axis represents runs where sensor footprint was large relative to dominant surface wave wavelength, resulting in limited spatial resolution, while the right end of the axis represents runs where surface waves were long relative to sensor footprint, so surface waves could be spatially resolved in water level record. Runs involving regular, single wavelength waves are specified by a red square, and runs with ocean-like waves, over a broader frequency range, are specified as black triangle.

Results for all sensors clearly show a relation between offset magnitude and surface wave wavelength to foot print ratio.

There is an increase in offset magnitude with decreasing wavelength to footprint ratio. In some cases, water level offsets as large as 5-7 cm are observed, but only during runs with very short, regular continuous waves, which are very unlikely to occur in nature. In most cases for runs where longer wavelength waves were present and surface waves were characterized by a broader band spectrum (and hence more realistic) offsets were typically within 1 cm.

Most notably, both the Sutron and the Miros performed well for all runs involving waves generated from the ocean-like spectrum, with offsets were within ± 1cm. Results were mixed for both the Design Analysis and Vega Puls sensors however. The Design Analysis performed well for three runs with ocean-like waves, where dominant waves were much larger than sensor footprint width (runs where sensor was lower, closer to water surface). Mixed results from the Ohmart Vega are more than likely a result of sensors not being setup optimally for this application, and results in the plot are skewed due to runs where the sensor appeared to lock onto crests and troughs of wave. This re-emphasizes the importance of using these results along with guidance from vendors to ensure sensors are setup optimally for future testing.

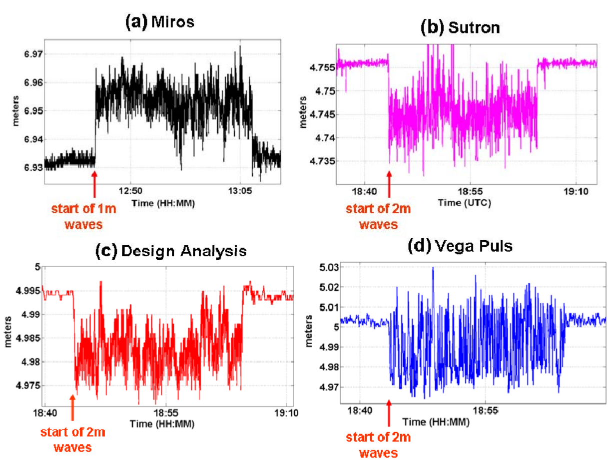

Figure 8. Various examples of shifts in microwave measured range to water surface that occur at the onset of wave generation; Range measured by (a) Miros, (b) Sutron, (c), Design Analysis, and (d) Vega Puls.

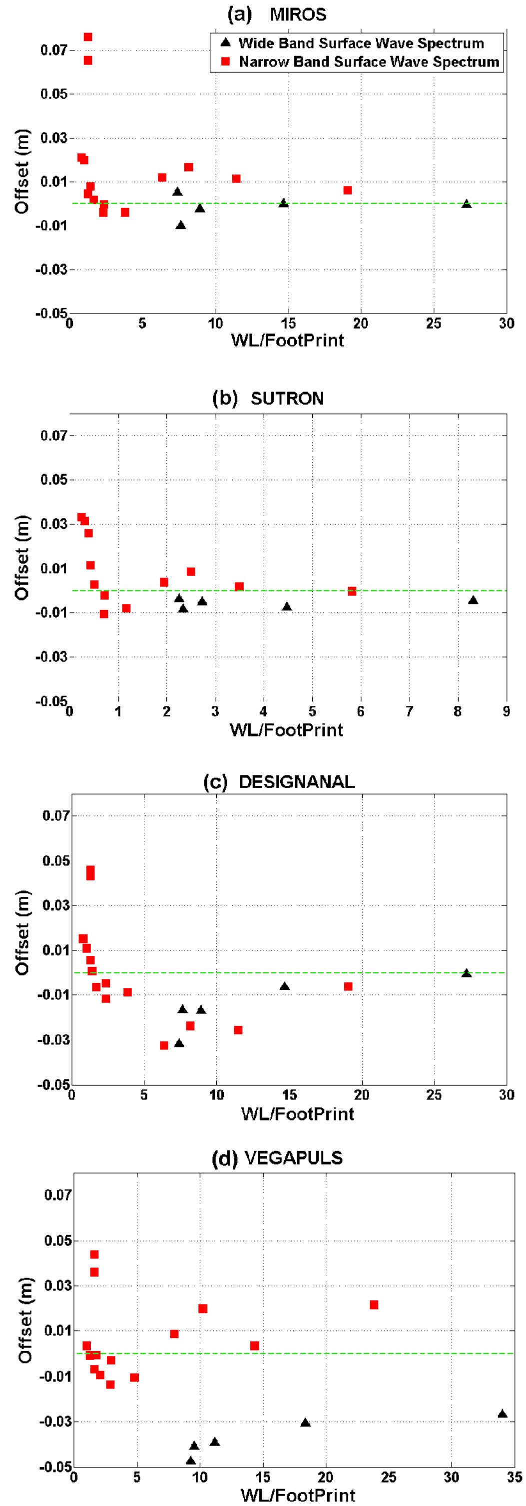

Figure 9. Calculated wave induced offsets in measured water level versus ratio between surface wave wavelength and sensor footprint size for each run; (a) Miros, (b) Sutron, (c), Design Analysis, and (d) Vega Puls. Red squares specify runs with regular wavelength waves (narrowband wave spectra) and black triangles runs with ocean like waves (wide surface wave spectra).

V. Summary And Recommendations

The experiment conducted by NOAA CO-OPS at the NSWC Mask Facility in Carderock, MD resulted in the collection of a unique and valuable data set for assessing impact of surface waves on MWWL sensors and for developing techniques for removing high frequency wave induced noise from MWWL records.

Presence of continuous, regular short wavelength waves revealed some limitations of the microwave sensors as shown by resulting offsets in water level measurements. However, for most test runs involving waves over generated over a broad range of frequencies (more representative of real conditions in the field), sensors performed well, measuring water levels within 1 cm in the presence of surface roughness. Wave induced offsets in water level measurements showed a dependency on wavelength/sensor footprint ratio, and band width of surface wave spectra.

The Miros and Sutron sensors were setup to apply minimal filtering to range measurements and no processing outside of 1 Hz time increments, resulting in better performance for this application. Both sensors measured water level within ± 1 cm accuracy, during all runs where ocean-like waves were generated, while both the Design Analysis and Ohmart Vega sensors showed mixed results due to time averaging/filtering settings that were not optimal for the application of measuring water level in the presence of high frequency gravity waves. Admittedly, inadequate information was known about these sensors' filtering and signal processing algorithms before the test was conducted and there is still potential for improved performance during future testing, once an optimal setup is implemented.

Microwave technology clearly offers many advantages over currently used sensors, but understanding the impact of surface waves on measurements and implementing data processing techniques to remove high frequency noise from long term water level records presents a new challenge. The currently implemented NOAA CO-OPS Data Quality Assurance Processing (DQAP) scheme, used to create final water level products from NWLON measurement stations involves smoothing 1 Hz water level data using a simple 181-second moving average centered on the hour and tenth-hour. Although this procedure is effective for data collected by currently used acoustic sensors, it may not be optimal for microwave sensors. NWLON acoustic sensors are typically deployed with a narrow calibration/sounding tube surrounded by a protective well. A 5 cm orifice at the base of the well acts as a partial filter eliminating a significant amount of high frequency surface wave motion from water level records before processing is applied. MWWL sensor measurements on the other hand, are made "in the clear" from above the water's surface with no physical components at or near the air-water interface. Thus it senses all surface motion, including oscillations at frequencies much higher than tidal frequencies. Recent observations of spectra of water level measurements obtained in the field do show a well-defined cusp of energy in the gravity wave frequency band (0.05 and 0.20 Hz, periods of 20 sec to 5 sec) as expected. Based on sensor design and these results, recommendations have been made for pre-filtering MWWL 1-Hz raw data prior to applying the DQAP moving average [5,8]. Recommended concepts involve low-pass filtering specifically designed to eliminate water level variance at or above a certain frequency. A type of numerical filter known as the finite impulse response (FIR) filter can be used to do this through application of a set of symmetric filter weights specifically chosen to deliver the desired filter response characteristics. In addition to the elimination of unwanted variance above the filter cutoff frequency, filtered data points benefit from reduced sample standard error with increased filter width (increased number of weights).

NOAA CO-OPS is continuing to test MWWL sensors in to demonstrate operational capabilities and quantify sensor accuracy across. Recent long term field testing has been initiated at several different test sites for the purpose of obtaining long water level records across a broad range of environmental conditions. These data and resulting analysis will be summarized and presented in subsequent reports, papers, and conferences as work progresses.

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